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AUTHOR Rodda, Michael; And Others
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ABSTRACT

The paper reviews research from 1970 to the present in the study of cognitive processing and language in deaf students and adults. Studies address the following topics: differential specialization (direct observation of clinical populations and indirect methods examining handedness, dichotic listening, and visual hemifield differences); cerebral specialization in hearing impaired populations (research with neurologically abnormal and normal hearing-impaired Ss); and experimental studies (studies of information transmission and laterality). The conflicting and contradictory nature of some findings is noted, and unanswered questions are summarized. It is concluded that data support the hypothesis that auditory experience is a determinant of language lateralization. (CL)

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COGNITIVE PROCESSING AND LANGUAGE IN DEAF STUDENTS: A DECADE OF RESEARCH

Michael Rodda, George Buranyi,
Ceinwen Cumming, and Beverly Muendel-Atherstone
University of Alberta

Abstract

During the 1970's two independent strands of research developed in the study of cognitive processing and language in deaf students and adults. Researchers such as Bellugi (Klima & Bellugi, 1979) and Wilbur (1979) have extensively studied the morphological, syntactical, and semantic bases of ASL. Other researchers, such as Conrad (1979), have studied the coding processes which operate in pre-categorical storage and/or short-term memory. Some attempts have been made to relate these processes to left-right hemispheric localization in the Central Nervous System, but the research findings on this point are inconclusive. This paper: (1) briefly reviews the research that has been undertaken in the last decade, and (2) attempts to bring some coherence to the conceptualization of cognitive and language-processing by reporting summations of various studies.

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Introduction

Despite intensive educational efforts, it is not uncommon for deaf students to lag behind their hearing peers in both the acquisition of verbal language and academic skills. Wilson (1977) suggested that this lag may result from differences in the organization of language at the cortical level. However, Lenneberg (1976) observed aphasia in deaf subjects with left-brain injury, and concluded that deaf individuals, like normally hearing individuals, have left-hemispheric dominance for language. Nevertheless, extrapolation of Lenneberg's findings to deaf adults and children in general has been severely criticized on the grounds that the adults studied do not constitute a representative sample. Variables such as age of onset of deafness, etiology, degree of hearing loss, premorbid language, and educational treatment are not usually controlled, and they exert a significant effect on the results obtained (Kelly & Tomlinson-Keasey, 1978). Therefore, not surprisingly, the results are contradictory. For example, Wilson's (1977) research provided no evidence of cerebral specialization for language in her deaf adult subjects. Phippard (1977) and Vargha-Khadem (1982) found that oral deaf subjects processed verbal information more advantageously in the right hemisphere.

Differential Specialization

Information concerning cerebral specialization for functions such as language processing has been forthcoming from research involving both direct observation of clinical populations and indirect methods of studying clinical and neurologically normal populations. Indirect methods have included studies of handedness, dichotic listening, and visual hemifield differences.

Direct Methods

Evidence favoring the differential specialization of the cerebral hemispheres in relation to functions such as language processing first came from clinical

studies of hearing patients with localized cerebral lesions (Hecaen, 1962), patients having undergone hemispherectomy (Basser, 1962; Smith, 1966; Krashen, 1972), and studies of split-brain or commissurotomized patients (Gazzaniga, 1969; Milner & Taylor, 1972; Nebes, 1974). However, studies of patients with damage in one or the other hemisphere are difficult to interpret because of the inaccurate match between right and left-hemisphere damaged groups for locus and extent of the injury (Nebes, 1974). Furthermore, as Semmes (1968) pointed out, assumptions about hemispheric dominance for certain tasks do not take into account that the neural substrate in one hemisphere may be more focally organized, with the result that limited damage will produce a greater deficit. In turn, this loss can lead to the dubious inference that a particular hemisphere is dominant for the capacity being tested.

Studies of commissurotomized patients, despite being open to criticism regarding control of variables such as age, sex premorbid intelligence, education, and motivation, have provided valuable information on hemispheric specialization and have produced some fairly consistent findings. Surgical division of the forebrain commissures leaves both hemispheres intact, allowing the experimenter to compare the performance of one hemisphere with that of the other. Research studies done with patients on whom such operative procedures have been used to alleviate epileptic symptoms indicate that, in addition to left-hemispheric dominance in language skills and right hemisphere dominance in visuospatial skills, the left hemisphere may be more specialized for analytical processing and the right hemisphere for gestalt processing (Bogen, 1969; Sperry, 1973; Nebes, 1974). In particular, studies of this type appear to demonstrate that the right hemisphere of commissurotomized patients is superior in generating a complete stimulus configuration from partial or fragmentary information (Nebes, 1971, 1972, 1973, 1974). However, the right hemisphere is not totally nonverbal and it does play a

vital role in the recovery of speech and language functioning in cases where the left hemisphere has been damaged or is malfunctioning (Searleman, 1977). Searleman's review of the literature also seems to suggest that the right hemisphere has speech comprehension capabilities, although right-hemispheric involvement in speech production is certainly limited.

Indirect Methods

Handedness studies of brain-damaged patients exemplify one type of indirect method used to study cerebral specialization. Such studies have shown that the left hemisphere is dominant for language in over 90 percent of right-handed people and in over 50 percent of left-handed people (Searleman, 1977). However, these percentages are lower when the studies involve neurologically normal populations.

Dichotic listening tests and visual hemifield studies have recently become the two most popular indirect methods of studying lateralization effects and both have been used with neurologically normal subjects. In dichotic listening, most right-handed people recall auditory stimuli presented to the right ear, indicating left-hemispheric specialization for language (Bryden, 1963, 1975). Similar results are obtained for hearing subjects in visual hemifield studies, but most of the important relevant research for this paper is with hearing-impaired subjects and is discussed in the next section.

Cerebral Specialization in Hearing-Impaired Populations

As with hearing populations, evidence concerning cerebral specialization has been obtained from both neurologically normal and neurologically abnormal deaf subjects. Not surprisingly, lateralization of language functions has been the focus of much of this research.

Research with Neurologically Abnormal Hearing-Impaired Subjects

Clinical reports of aphasia and paralysis of the right side in hearing-impaired subjects found to have suffered left-sided brain injury and associated language disfunction have been interpreted as supporting the view that language is lateralized in the left hemisphere for hearing-impaired individuals (Lenneberg, 1967; Sarno, Swisher, & Sarno, 1969). However, the rarity of such cases, the possibility of bias in the selection of subjects, and the subsequent inability to control confounding factors make it difficult to draw firm conclusions.

McKeever, Hoemann, Florian, and Van Deuenter (1976) commented on the clinical literature, and noted that patients showed greater impairment of the expressive aspects of language rather than of comprehension. They also noted that the degree of aphasia was not profound even after relatively short recovery periods. Studies of normally hearing subjects by Kimura (1973) indicate a left-hemisphere involvement in hand gestures accompanying oral speech, and when Kimura (1976) examined seven cases of deaf aphasia cited in the literature, she noted an association of manual communication disorder (sign language) with left-hemisphere control of complex motor behavior rather than of language, and the analysis of McKeever, Hoemann, Florian, and Van Deuenter supports this hypothesis. Thus, if expressive rather than comprehension skills are affected by left hemispheric damage, patients may be demonstrating motor skill deficits rather than aphasia. Kimura, Battison, and Lubert (1976) provided additional support for this hypothesis in their study of a deaf aphasic who showed impairment of nonlinguistic hand movements. The authors stated: "It is quite possible that the degree of impairment seen in our subject on the linguistic hand movements parallels that of the nonlinguistic--that is, that his defect is primarily one of motor sequencing" (p. 571).

Research with Neurologically Normal Hearing-Impaired Subjects

Recent research involving neurologically normal hearing-impaired subjects has been illuminating concerning hemispheric specialization in such individuals. Employing tachistoscopic presentation of verbal and nonverbal stimuli to the visual hemifields, Phippard (1977) found that a group of deaf subjects taught by oral methods had a right-hemisphere advantage in perceiving both verbal and nonverbal material. A group of subjects taught by a combination of oral and manual techniques showed no evidence of lateralization. The results can be interpreted to suggest that the type of communication methods used in schools may affect how the cerebral hemispheres organize themselves, although it is equally possible that the differences result from more basic physiological differences.

McKeever, Hoemann, Florian, and Van Deuenter (1976) designed a study to investigate the importance of auditory experience in determining language lateralization. They noted that previous studies had shown that the auditory association cortex was larger in the left than in the right hemisphere (Geschwind & Levitsky, 1968)--a factor that could play a role in the tendency of language processes to lateralize in the left hemisphere. Their basic premise was that auditory experience plays a major causal role in the tendency of language functions to lateralize within the left hemisphere. Their results indicated that when stimuli are bilaterally presented, deaf subjects show minimal hemifield asymmetry for both English word and ASL stimuli. With unilateral presentation, deaf subjects showed a left-hemisphere advantage for the recognition of words.

In discussing lateralization effects, McKeever, Hoemann, Florian, and Van Deuenter (1976) stated that as the task becomes more complicated, there is less dominance in one hemisphere in deaf subjects. However, Wilson (1977) in an unpublished study suggests that this finding is a strategy effect unrelated to cerebral dominance, and that subjects presented with bilateral stimuli decide to

either shadow the right or left channel. Some other cautionary notes are in order concerning the study by McKeever, et al. It employed deaf undergraduate students, and few deaf individuals reach this level of education. Therefore, not only was the sample unrepresentative, but it was linguistically superior to the large majority of the deaf population. The subjects in the study were also all female. Buffery and Gray (1972) have noted that there are sex differences in verbal and spatial skills, and these could conceivably affect the pattern of cerebral asymmetry found by McKeever.

A study using bilateral presentation of sign and word stimuli by Manning, Goble, Markman, and LaBreche (1977) showed deaf subjects to have weaker left-hemisphere superiority for words than hearing subjects, although there was still a tendency for deaf subjects to lateralize words in the left hemisphere. The deaf subjects also had an insignificant tendency to superior right-hemisphere recognition of signs, which shifted to superior left-hemisphere recognition of signs when word/sign combinations were presented. The authors suggest that translation of signs to English or of words to signs could be responsible for obscuring the evidence of strong lateralization effects for these stimuli.

In one of the few studies not employing the visual hemifield methodology, LaBreche, Manning, Goble, and Markman (1977) used bilateral tactual exploration of letters and nonsense shapes. They found that both deaf and normal hearing groups had a tendency towards right tactual field recognition of shapes. These results were supported in another well-controlled study by Vargha-Khadem (1982). Using dichaptic presentation, she found no lateralization effects for nonsense syllables, but a right tactile field advantage for letter shapes in both hearing and deaf subjects.

Wilson (1977), using unilateral presentation of stimuli to the visual hemifields, found no cerebral asymmetry effects in deaf subjects for the processing of

words, letters, or signs. These findings tend to substantiate the view that left-hemisphere superiority for language in hearing subjects results from auditory input to the left auditory association cortex of the brain. Wilson also found that signed stimuli are easier to identify than printed stimuli when the exposure time was brief (20 msec). She interprets this result as being due to the slower decay of spatial information, when compared to the decay of "figural" information.

Kelly and Tomlinson-Keasey (1977) found that deaf children had a tendency to process words and pictures faster in the right hemisphere. They employed words and picture stimuli containing abstract as well as concrete items, and they presented them singly to the visual hemifields. Reaction times were also measured for the subjects' decisions about whether or not stimulus pairs matched. They found that deaf children processed words and pictures of abstract and concrete content with equal facility, and, therefore, they concluded that the children processed all stimuli using visual codes. This conclusion was supported by the data on normally hearing subjects who processed word stimuli faster than pictorial stimuli in both hemispheres. In a second but similar study, Kelly and Tomlinson-Keasey (1978) again found that deaf children processed both verbal and iconic stimulus codes equally well in the right hemisphere. Finally, Poizner, Battison, and Lane (1979) used tachistoscopic presentation of moving signs by making up three frames of "super 8" film with a total exposure time of 111 m/sec. They replicated other results with words and static signs, but found no hemispheric dominance with moving signs. As they point out, their stimuli did not manipulate the variables in ASL which are right hemisphere dominant--for example, facial expression and body tilt--and, therefore, it is possible that different attributes of ASL are localized in different hemispheres. If so, this result would explain the conflicting data which is found in different studies.

The possibility that deaf subjects rely on visual codes is also supported by studies of short-term memory in which subjects make more formational errors, while the hearing make semantic errors (Bellugi, Klima & Siple, 1975; Wallace, 1972). The study by Wallace (1972) does, however, suggest that the deaf make use of other codes. He found that orally-trained subjects showed some evidence of using an articulatory code, while manually-taught subjects used a code based partly on fingerspelling. He also noted that the deaf performed better than the hearing on a facial recognition task--again stressing the importance of the visual channel (see Conrad, 1979, for a major treatise in this area). The use of different encoding strategies has been explored by Boshoven, McNeil, and Harvey (1982). They relate these differences to hemispheric specialization for various functions, and suggest, for example, that in processing drawings deaf subjects may use non-verbal referents, whereas hearing subjects use verbal referents. Overall, they suggest that the deaf group may have adopted holistic/gestalt processing strategies, whereas hearing subjects might use more analytical strategies.

Experimental Studies

The authors of this paper have been involved in a number of studies of various aspects of language and cognition (Grove, O'Sullivan, & Rodda, 1979; Rodda & Grove, 1982). The primary stimuli used in these studies are a series of sentences (test items) developed as part of a Test of Communication Skill. Two particular studies will be described in an attempt to increase our understanding of the complex interactive processes which take place between cognition and language.

Studies of Information Transmission

1) Response Latency

The time taken to respond to a stimulus (including transmission time) is a useful way of measuring the overall differences in cognitive-processing strategy.

In one study by Rodda and Grove (1982), the overall average latency of response to signed and orally communicated sentences was calculated. Figure 1 shows this latency (t) plotted against total scores (TS). The mean response time per item for the orally presented material was 14.5 secs, and for material presented using total communication was 18.4 secs. However, the regression functions for the two groups were clearly different:

Total: $TS = 0.871 - 0.0044t$ $r = -0.31$ n.s. (A)

Oral: $TS = 1.04 - 0.023t$ $r = -0.61$ n.s. (B)

With so few degrees of freedom, two-tailed t-tests fail to reach significance, but the trend seems to be fairly clearly established: (1) for total communicators, the total score is virtually independent of latency, and a very slow responder achieves about the same total score as a fast responder; and (2) for oral communicators, there are indications of a moderately strong negative relationship between the two variables. A slow-to-respond oral subject is also likely to be a low scorer. One implication of these data seems to be that the considerable cognitive load imposed by lipreading reduces the capacity available for short-term retention and processing. This effect might also explain why the subjects in our study (who were tested using very brief messages) exhibited less of an effect of communication method than the subjects of White and Stevenson (1975), who were presented with relatively long passages. The data also support Wilson's (1977) suggestion that some of the studies reporting lateralization effects are really measuring the use of different encoding and problem-solving strategies.

2) Rate of Information Transfer

The differential relationship described in the previous paragraph led in another study (Rodda & Grove, 1982) to the development of an estimate of the rate at which information is transmitted during testing. One hypothesis examined was that some of the differences between methods of communication, as assessed by a

Figure 1

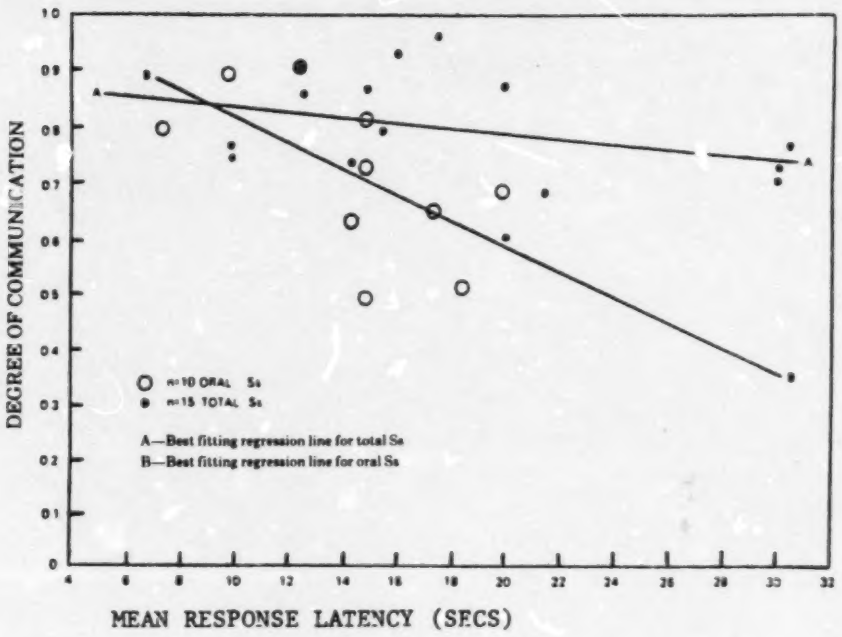
DEGREE OF COMMUNICATION
MEAN RESPONSE LATENCY (SECS)
A—Best fitting regression line for total Ss
B—Best fitting regression line for oral Ss

Figure 1. Score as a function of the time taken to respond to signed or spoken messages (including the presentation time)

total percentage score, reflected a time-related "tradeoff" mechanism. High scores were obtained by the students using "Reading" and the students using "Total Communication," but it might be that "readers" and "total communicators" show slower response times than subjects using Oral Communication.

The arbitrary metric employed to assess such effects was the Information Transfer Rate (ITR), defined as the number of messages correctly responded to per minute of testing time. Table 1 shows the mean ITR as a function of two age groups (9-13 years and 14-20 years) and method of communication. The data came from an adjusted sample within which the mean age of four different communication groups (Oral, Total, Manual, and Reading) was precisely balanced (11.8 years). A square root transformation was used to provide a good fit to the normal distribution (x^2=2.79 on 4 d.f., n.s.).

Table 1

Information Transfer Rate (ITR: messages correct/minute)
As a Function of Age and Method of Communication

Communication Method:	Reading	Total	Oral	Manual
Younger Age Group	2.10	1.77	0.95	1.74
Older Age Group	2.61	2.45	1.72	2.27
All Subjects	2.39	2.07	1.36	2.07
Number in Younger Group	9	14	8	8
Number in Older Group	12	11	9	13

Contrary to the hypothesis just considered, the overall superiority of Reading and the relative weakness of the Oral Method are emphasized when the transmission rate is taken into account. However, the mean ITR rates for Total and Manual Methods of Communication were almost identical. The overall effect of

the Communication Method was very highly significant: $F(3,76) = 8.54$, $p < 0.001$, as was the effect of age: $F(1,76) = 17.30$, $p < 0.001$. However, the interaction was not significant ($F < 1$).

Laterality Studies

In a study by Muendel-Atherstone and Rodda (1983), signed and unsigned stimuli were visually presented to 20 hearing and 20 prelingually deaf adults. Materials were presented unilaterally in a randomized sequence to both right and left visual hemifields through a two-field tachistoscope. Hearing and deaf subjects differed significantly in the number of correctly identified stimuli, with hearing subjects scoring higher on all 6 types of materials presented--pictures of (1) written letters, (2) written words, (3) signed letters, (4) signed words, (5) signed idioms, and (6) road signs. The materials were factored for hearing subjects only and then for deaf subjects only. Four factors were found in the hearing subjects' responses and 3 factors in the deaf subjects' responses.

The four factors identified in the hearing subject's responses (Table 2) were accounted for by eigenvalues and percent variance follows: Factor 1 (2.94; 42.1%), Factor 2 (2.11; 30.3%), Factor 3 (1.08; 15.5%), and Factor 4 (0.83; 12.0%). The first factor included all the ASL signs; the second factor included

Table 2

Factor Analysis of Materials Presented to Hearing Subjects

Materials	Factor 1 (Signed presentations)	Factor 2 (Left unsigned materials)	Factor 3 (Right road signs)	Factor 4 (Right letters)	h^2_j
Letters L	0.17	0.89	-0.14	-0.05	0.83
Letters R	-0.12	-0.06	-0.08	0.75*	0.59
Words L	0.01	0.65*	-0.01	-0.09	0.43
Words R	-0.43*	-0.02	0.17	-0.10	0.23

(table continues)

Materials	Factor 1 (Signed presentations)	Factor 2 (Left unsigned materials)	Factor 3 (Right road signs)	Factor 4 (Right letters)	h^2j
S Letters L	0.47*	0.18	-0.22	-0.10	0.32
S Letters R	0.73*	-0.16	-0.13	-0.22	0.62
S Words L	0.49*	0.43	-0.02	-0.05	0.43
S Words R	0.68*	0.10	-0.05	-0.04	0.47
S Idiom L	0.63*	-0.19	0.27	-0.44	0.70
S Idiom R	0.66*	0.27	0.38	-0.24	0.71
Road Sign L	-0.05	0.87*	0.48	0.03	0.99
Road Sign R	-0.19	0.02	0.78*	0.05	0.65

* Probability @ < 0.01.

presentations to the left hemifield of letters, words, and road signs; the third factor included road signs with right presentation only; and the fourth factor consisted of letters presented to the right hemisfield.

The three factors identified in the deaf subjects responses (Table 3) accounted for eigenvalues and percent of variance as follows: Factor 1 (4.42; 56.4%), Factor 2 (1.94; 24.8%), and Factor 3 (1.48; 18.8%); and they appeared to be more clearly defined. The first factor included only the ASL signs, the second factor consisted of left and right presentation of road signs, and the third factor consisted of letters presented to the right and left hemifields. The data provide interesting confirmation of Hoemann's (1978) hypothesis that fingerspelled symbols are an integral part of sign language. In deaf subjects, performance on fingerspelled letters correlated highly with performance on sign language symbols.

As there was no difference between the materials presented to the left and right visual hemifields, we find substantiation for the hypotheses that (1) the deaf sign subjects would show an overall reduced laterality effect, and (2) that

Table 3

Factor Analysis of Materials Presented to Deaf Subjects

Materials	Factor 1 (Signed presentations)	Factor 2 (Road signs)	Factor 3 (Letters)	h^2_j
Letters L	0.14	-0.12	0.74*	0.58
Letters R	-0.15	-0.08	0.94	0.91
Words L	-0.13	0.34	-0.09	0.14
Words R	0.19	0.35	-0.14	0.17
S Letters L	0.80*	-0.21	0.10	0.70
S Letters R	.85*	-0.31	-0.17	0.85
S Words L	0.95*	0.22	0.01	0.95
S Words R	0.74*	-0.21	0.09	0.59
S Idiom L	0.81*	0.01	-0.16	0.68
S Idiom R	0.79*	-0.08	0.22	0.68
Road Sign L	-0.18	0.74*	-0.06	0.59
Road Sign R	-0.12	0.99*	0.08	0.999

* Probability @ < 0.01.

hearing sign subjects would also show bilateral functioning. More road signs were correctly perceived in the right visual hemifield (left hemisphere) in both groups, and there was a tendency in all groups to more correctly identify materials presented to the left hemisphere.

Discussion and Conclusions

While previous research into cerebral lateralization of language with hearing-impaired populations has provided some conflicting results and has been open to criticism, it does indicate that the field has promising potential for increasing our understanding of cognitive processing in both hearing and deaf individuals. If deaf individuals acquire a different cerebral organization for language as compared to hearing populations, then such differences could have a

considerable impact on the intervention methods used with young children. Myklebust (1964) hypothesized that the absence of a sensory modality could alter the integration and function of the other senses. Liberman (1974) has similarly suggested that the left hemisphere becomes specialized as a result of the grammatical coding involved in speech perception, thus stressing the importance of auditory experience for language lateralization. That argument also has been presented more recently by Conrad (1980) and Arnold (1983) with a specific focus on the neurological implications of reduced auditory input.

Even if language is not lateralized differently in deaf children, adolescents, and/or adults, a number of important questions remain to be answered. For example, does the acoustic code have unique properties or can the signs of a visually-based language, such as American Sign Language, fulfill the same tasks? If such signs can be utilized equally well in the acquisition of language structures, will this acquisition occur in the same way as it does with an acoustic code? Another question concerns how a language such as ASL is processed by both deaf and hearing populations. Are signs mediated equally well by both hemispheres? If so, this mediation could have significance for intervention, not only with deaf children but with hearing aphasics who could learn sign language as a means of communication. However, it may be that educational experiences result in patterns of atypical lateralization in deaf subjects. Since atypical lateralization has been associated with cognitive and perceptual deficits in hearing populations (Levy & Reid, 1978), it is also possible that the language problem associated with early prelingual deafness may be a consequence of educational deficits rather than neurological differences.

Hemispheric Specialization

The overall results of present research tend to lend support to the hypothesis that auditory experience is a determinant of language lateralization--that is,

deaf respondents show less hemispheric lateralization for processing of letters and words than normal hearing subjects. They also seem to be less laterally specialized for spatial processing. In reaching this conclusion, it should be noted that the results from tachistoscopic studies contradict clinical reports based on studies of aphasic individuals. However, the clinical studies are difficult to interpret because of methodological weaknesses, even though there are also some problems with studies using tachistoscopic presentation of stimuli to the visual hemifields. The degree of hearing loss and age of onset of hearing loss are sometimes controlled in the tachistoscopic studies, but little control is exercised over variables such as: the educational training received by the subject (Oral, Manual, or Total), the possible influence of sex differences, and whether or not developmental patterns are the same in the hearing and deaf populations. Indeed, when such variables are controlled, the results vary for different groups. For example, Phippard (1977) used tachistoscopic presentation of verbal and nonverbal visual stimuli to the visual hemifields. She found that a group of deaf subjects taught by oral methods had a right-hemisphere advantage for the perception of both verbal and nonverbal material, while a similar group trained in a combination of oral and manual techniques showed no laterality effects. Finally, a further problem is the representation of sign stimuli through the use of line drawings. Such drawings fail to convey dimensions of movement and spatial relationships, both of which are important in communicating in ASL, and studies using film and movement such as those of Poizner, Battison, and Lane (1979) are rare. Nevertheless, the weight of the evidence supports the premise that specialization for language functions is somewhat different in the deaf population.

Auditory and Visual Coding Systems

Several of the tachistoscopic studies have made note of the reliance of deaf individuals on visual codes and the possible effect of such a coding strategy on lateralization. However, tachistoscopic studies may be particularly amenable to using a visual strategy; and assumptions based on these studies may not be applicable outside the experimental context. For example, the hearing-impaired may indeed use visual codes when confronted with briefly presented stimuli; but they may change their coding strategy if the sequence of stimuli is longer. Furthermore, as Armstrong (1983) has lucidly argued, iconicity is not a uniquely visual phenomenon. He points out that the development of spoken languages has incorporated iconic elements, and cross refers to the argument of Armstrong and Katz (1981) that left hemispheric dominance is a function of increasing social complexity.

The adoption of different coding strategies may result partly from perceptual confusion and partly from short-term memory overload. Oral reception depends upon a signal which is fragmented and of poor quality when compared with manual signs, Total Communication, or the printed stimulus. In order to compensate for missing or ambiguous elements, the deaf person communicating orally must involve himself in a complex interpolatory process: he must rapidly identify the message context, form hypotheses about possible alternative meanings, and constantly check out these hypotheses as more message information becomes available. Given that his knowledge of syntax is often defective and that processing sequential information presents him with special and as yet poorly understood additional problems, reception probably draws upon higher-level cognitive resources to perform tasks normally accomplished by lower-level perceptual mechanisms. Indeed, analysis of rates of information transfer indicates that the Oral Method is not only generally

less effective, but also generally slower. In contrast, Manual and Total modes of receptive communication seem to provide a less fragmented signal.

One intriguing finding in our own data was that Total Communication displays zero STM loss for relatively brief messages (as inferred from the regression of total score upon communication time). There are three possible explanations for this finding: (1) if two independent traces (corresponding to the oral and manual inputs) are created, recall probability will increase; (2) a dual signal may facilitate semantic recoding, perhaps because fewer higher level processes are required in order to remove ambiguity; and (3) during input, the receiver may be able to alternate his attention between lip and hand movements, thus enabling him to select the least ambiguous component at each stage during the transmission of the message. These possibilities could all apply separately or in combination, and the situation may be complicated by individual differences in strategy in response to the demands of a particular task. However, deaf persons do seem to possess adequate cognitive skills to enable them to divide their capacity between oral and manual input channels (Duncan, 1980); and, in a practical context, the information transfer rate for Manual and Total Methods seem to be the same. Which of the two is "best" will depend upon the requirements of the moment. Since Total Methods convey more information, albeit more slowly, they may be preferred for instructional purposes, whereas in everyday social interaction, Manual Methods might be more appropriate.

Conrad's (1979) work, which links oral skill with modes of STM encoding, may provide at least a partial answer to questions about short-term coding strategies. Reception using oral communication can be regarded as an active "disambiguating" process. Therefore, we would expect syntactical and verbal reasoning ability to correlate with oral skill. Indeed, Arnold and Walter (1979) have shown that

lipreading test scores correlate significantly with verbal reasoning skills. They also found ratings of oral skill to be linked both with various cognitive measures (including vocabulary, comprehension, and numerical skill) and the degree of hearing impairment involved (and, by implication, mode of encoding). In contrast, neither IQ (White & Stevenson, 1975) nor measures of abstract or mechanical reasoning (Arnold & Walter, 1979) are predictive of oral receptive performance.

In conclusion, it seems that the communicative efficiency of any given method of communication is not determined by the extent to which it conforms to the syntax of spoken language (reading and oral communication come respectively first and last in the ranking of efficiency). Efficiency appears to be related to peripheral processing characteristics--in particular, the presence or absence of fading, spatial versus sequential display, signal/noise ratio, and STM demand. Syntactical difficulty may add to or detract from relative performance, but it seems to be encountered in both the visual and auditory modalities. Central processing seems, in turn, to reflect these differences and to vary from subject group to subject group. Bilateral representation of both an acoustic and a visual code seems to be more characteristic of hearing-impaired subjects, but whether this effect is educationally or physiologically determined is, as yet, unclear.

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